Course Title: **Radiological Control Technician**
Module Title: **Physical Sciences**
Module Number: **1.03**

Objectives:

1.03.01 Define the following terms as they relate to physics:
- a. Work
- b. Force
- c. Energy

1.03.02 Identify and describe four forms of energy.

1.03.03 State the Law of Conservation of Energy.

1.03.04 Distinguish between a solid, a liquid, and a gas in terms of shape and volume.

1.03.05 Identify the basic structure of the atom, including the characteristics of subatomic particles.

1.03.06 Define the following terms:
- a. Atomic number
- b. Mass number
- c. Atomic mass
- d. Atomic weight

1.03.07 Identify what each symbol represents in the ${}^{A}_{Z}X$ notation.

1.03.08 State the mode of arrangement of the elements in the Periodic Table.

1.03.09 Identify periods and groups in the Periodic Table in terms of their layout.

1.03.10 Define the terms as they relate to atomic structure:
- a. Valence shell
- b. Valence electron

References:

1. "Nuclides and Isotopes"; Fourteenth Edition, General Electric Company; 1989.
2. "Modern Physics"; Holt, Rinehart and Winston, Publishers; 1976.
3. "Chemistry: An Investigative Approach"; Houghton Mifflin Co., Boston; 1976.
4. "Chemical Principles with Qualitative Analysis"; Sixth ed.; Saunders College Pub.; 1986.
5. "Introduction to Chemistry" sixth ed., Dickson, T. R., John Wiley & Sons, Inc.; 1991.
6. "Matter"; Lapp, Ralph E., Life Science Library, Time Life Books; 1965.
7. "Physics"; Giancoli, Douglas C., second ed., Prentice Hall, Inc.; 1985.
8. DOE/HDBK-1015 "Chemistry: Volume 1 of 2"; DOE Fundamentals Handbook Series; January 1993.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Chart of the Nuclides
5. Periodic Table of the Elements
6. Lessons Learned

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

B. Motivation

It is important to a RCT that they have a basic understanding of physics because they may work in an environments where materials can undergo changes in state, resulting in changes in the work environment.

C. Overview of Lesson

1. Physics definitions
2. Law of Conservation of Energy
3. The Atom
4. Periodic Table
5. Valence Electrons

D. Introduce Objectives — O.H.: Objectives

II. MODULE OUTLINE

A. Work and Energy

Physics is the branch of science that describes the properties, changes, and interactions of energy and matter. This unit will serve as a brief introduction to some of the concepts of physics as they apply to the situations that may be encountered by RCTs. A general definition of matter is anything that has mass and occupies space. Energy can be understood by relating it to another physical concept - work.

1. Work and Force — Objective 1.03.01

   a. Work is defined in physics as a force acting through a distance.

   b. A force is a push or a pull. A more technical definition of force is any action on an object that causes the object to change speed or direction.

   c. Units

      (1) Force is derived as the product of mass and acceleration.

      (2) The SI derived unit is expressed in terms of newtons, (N)

$$N = \frac{Kg \times m}{s^2}$$

      (3) Mathematically, work is expressed as:

W = F x d

where:

W = Work

F = Force (newtons)

d = Distance (meters)

      (4) The SI unit of work is the joule (J).

      (5) One joule of work is performed when a force of one newton is exerted through a distance of one meter.

      (6) Thus:

$$J = N \times m$$

B. Energy

1. Energy is defined as the ability to do work. — Objective 1.03.02

a. Kinetic energy describes the energy of motion an object possesses. For example, a moving airplane possesses kinetic energy.

$$E_K = \frac{1}{2}mv^2$$

Where:

m = mass

v = velocity

b. Potential energy indicates how much energy is stored as a result of the position or the configuration of an object. For example, water at the top of a waterfall possesses potential energy.

$$E_P = mgh$$

Where:

m = mass

g = free fall acceleration

h = vertical distance

c. Thermal energy describes the energy that results from the random motion of molecules. For example, steam possesses heat energy.

d. Chemical energy describes the energy that is derived from atomic and molecular interactions in which new substances are produced. For example, the substances in a dry cell provide energy when they react.

2. Law of Conservation of Energy — Objective 1.03.03

a. The Law of Conservation of Energy states that the total amount of energy in a closed system remains unchanged. Stated in other terms, as long as no energy enters or leaves the system, the amount of energy in the system will always be the same, although it can be converted from one form to another.

b. Gasoline contains chemical energy that is released in the form of heat when a chemical reaction (burning) with oxygen occurs. This energy comes from the breaking and making of bonds between atoms. New products, carbon dioxide and water, are formed as the gasoline combines with oxygen. The energy of the burning gasoline produces heat energy which causes the gaseous combustion products to do work on the pistons in the engine. The work results in the vehicle moving, giving it kinetic energy.

c. Units

(1) Thermal energy is often measured in units of calories (CGS) or British Thermal Units or BTUs (English).

(a) A calorie is the amount of heat needed to raise the temperature of 1 gram of water by 1 EC. One calorie is equal to 4.18605 joules.

(b) A BTU is the amount of heat needed to raise the temperature of 1 pound of water by 1 EF. One BTU is equal to 1.055E3 joules.

(2) Electrical energy is sometimes expressed in units of kilowatt-hours. One kw-hr is equal to 3.6E6 joules

(a) A very small unit used to describe the energy of atomic and subatomic size particles is the electron volt (eV). One electron volt is the amount of energy acquired by an electron when it moves through a potential of one volt.

(b) It takes about 15.8 eV of energy to remove an electron from an atom of argon.

(c) Superunits such as kiloelectron volt (keV) and megaelectron volt (MeV) are used to indicate the energies of various ionizing radiations.

d. Work-Energy Relationship

(1) When work is done by a system or object, it expends energy. For example, when gaseous combustion products push against the pistons, the gas loses energy. The chemical energy stored in

the gasoline is used to do work so that the car will move.

(2) When work is done on a system or object, it acquires energy.

(3) The work done on the car by the combustion of the gasoline causes the car to move, giving it more kinetic energy.

(4) When energy is converted to work or changed into another form of energy, the total amount of energy remains constant. Although it may appear that an energy loss has occurred, all of the original energy can be accounted for.

(5) Consider the example of the automobile. The energy stored in the gasoline is converted to heat energy, some of which is eventually converted to kinetic energy. The remainder of the heat energy is removed by the engine's cooling system. The motion of the engine parts creates friction, heat energy, which is also removed by the engine's cooling system. As the car travels, it encounters resistance with the air. If no acceleration occurs, the car will slow down and the kinetic energy is converted to friction or heat energy. The contact of the tires on the road converts some of the available kinetic energy to heat energy (friction), slowing down the car. A significant amount of the energy stored in the gasoline is dissipated as wasted heat energy.

See Fig. 1 - "Energy Conversion in an Automobile"

e. Energy-mass relationship

Energy can also be converted into mass and mass converted into energy. This topic will be discussed further in Section 1.04 Nuclear Physics.

C. Energy and Change of State

Objective 1.03.04

1. Matter is anything that has mass and takes up space.

2. There are three states of matter)solid, liquid and gas.

See Table 1 - "State of Matter Compared" and Fig. 2 - "States of Matter"

3. Solid State

   a. A solid has definite shape and volume. The solid state differs from the liquid and gaseous states in that:

      (1) The molecules or ions of a solid are held in place by strong attractive forces.

      (2) The molecules still have thermal energy, but the energy is not sufficient to overcome the attractive forces.

      (3) The molecules of a solid are arranged in an orderly, fixed pattern.

4. Liquid State

   (a) When heat is added to a substance, the molecules acquire more energy, which causes them to break free of their fixed crystalline arrangement. As a solid is heated, its temperature rises until the change of state from solid to liquid occurs.

   (b) The volume of a liquid is definite since the molecules are very close to each other, with almost no space in between. Consequently, liquids can undergo a negligible amount of compression. However, the attractive forces between the molecules are not strong enough to hold the liquid in a definite shape. For this reason a liquid takes the shape of its container.

   (c) High energy molecules near the surface of a liquid can overcome the attractive forces of other molecules. These molecules transfer from the liquid state to the gaseous state. If energy (heat) is removed from the liquid, the kinetic energy of the molecules decreases and the attractive forces can hold the molecules in fixed positions. When compared with the kinetic energy, the attractive forces are not strong enough to hold the molecules in fixed positions, forming a solid.

5. Gaseous State

   (a) If the temperature of a liquid is increased sufficiently, it boils)that is, molecules change to the gaseous state and escape from the surface. Eventually, all of the liquid will become a gas.

(b) A *gas* has both indefinite shape and indefinite volume. A large space exists between gas molecules because of their high thermal energy. This allows for even more compression of a substance in the gaseous state.

D. The Atom

Objective 1.03.05

1. The Bohr Model was described by Ernest Rutherford and Niels Bohr - 1911

See Fig. 3 - Atomic Model

a. Made of protons, neutrons, and electrons

b. Central core called the nucleus

c. Contains protons and neutrons

d. Nuclear forces hold nucleus together

2. Protons

a. Positively charged (+1)

b. Mass = 1.6726 x 10^{-24} gm or 1.007276470 amu

c. Each element is determined by the number of protons in its nucleus. All atoms of the same element have the same number of protons.

3. Neutrons

a. Neutrally charged (0)

b. Mass = 1.6749 x 10^{-24} gm or 1.008665012 amu

c. Determines the isotope of an element. Same number of protons (therefore, of the same element) but different number of neutrons. Does not affect chemical property of element.

4. Electrons

a. Negatively charged (-1)

b. Small mass = 9.1085 x 10^{-28} or 0.00054858026 amu (. 1/1840 of a proton)

c. The mass of an electron is so small as compared to that of a proton or neutron, virtually the entire mass of an atom is furnished by the nucleus.

d. Number of electrons is normally equal to the number of protons (atom is electrically neutral)

e. The number of electrons in the outermost shell determines the chemical behavior or properties of the atom.

E. The Elements

1. Even though all atoms have the same basic structure, not all atoms are the same. There are over a hundred different types of atoms. These different types of atoms are known as elements. The atoms of a given element are alike but have different properties than the atoms of other elements.

2. Elements are the simplest forms of matter. They can exist alone or in various combinations. Different elements can chemically combine to form molecules or molecular compounds. For example, water is a compound, consisting of water molecules. These molecules can be decomposed into the elements hydrogen and oxygen. The elements hydrogen and oxygen are fundamental forms of matter. They cannot be further separated into simpler chemicals.

3. Chemical Names

a. Currently, there are 109 named elements. Some have been known for many centuries, while others have only been discovered in the last 15 or 20 years. Each element has a unique name. The names of the elements have a variety of origins. Some elements were named for their color or other physical characteristics. Others were named after persons, places, planets or mythological figures.

See Table 2 - "List of Elements by Name"

b. For example, the name chromium comes from the Greek word chroma, which means "color." Chromium is found naturally in compounds used as pigments. The elements curium, einsteinium, and fermium were named after famous nuclear physicists. Germanium, polonium and americium, were named after countries. Uranium, neptunium and plutonium are named in sequence for the three planets Uranus, Neptune and Pluto.

4. Chemical Symbols

See Table 2 - "List of Elements by Name"

For convenience, elements have a symbol which is used as a shorthand for writing the names of elements. The symbol for an element is either one or two letters taken from the name of the element. Note that some have symbols that are based on the historical name of the element. For example, the symbols for silver and gold are Ag and Au respectively. These come from the old Latin names argentum and aurum. The symbol for mercury, Hg, comes from the Greek hydrargyros which means "liquid silver."

F. Nomenclature

Objective 1.03.06

1. Atomic Number

   a. The number of protons in the nucleus of an atom.

   b. All atoms of a particular element have the same atomic number.

   c. Atomic numbers are integers.

   d. Atomic number for hydrogen is 1.

   e. A helium atom has two protons in the nucleus, which means that its atomic number is 2.

   f. Uranium has 92 protons in the nucleus, and has an atomic number of 92.

2. Mass Number

   a. The total number of protons plus neutrons in the nucleus of an isotope of an element is called the mass number.

   b. Since a proton has a mass of 1.0073 amu, we will give it a mass number of 1.

   c. The mass number for a neutron is also 1, since its mass is 1.0087 amu.

   d. By adding the number of protons and neutrons we can determine the mass number of the atom of concern.

      (1) A Normal hydrogen atom has 1 proton, but no neutrons. Therefore, its mass number is 1.

(2) A helium atom has 2 protons and 2 neutrons, which means it has a mass number of 4.

(3) If a uranium isotope has 146 neutrons, then it has a mass number of 238 (92 + 146). If it only has 143 neutrons its mass number would be 235.

e. The mass number can be used with the name of the element to identify to which isotope of an element we are referring, such as Uranium-235, Uranium-238 (often shortened to U-235 and U-238).

3. Atomic Mass

a. The actual mass of a particular isotope.

b. The units are expressed in Atomic Mass Units (AMU)

(1) AMUs are based on 1/12 of the mass of a carbon-12 atom, which has an atomic mass of 12 amu.

(2) The mass of a hydrogen atom is 1.007825 amu (1 proton + 1 electron)

(3) The mass of a Uranium-238 atom is 238.0508 and the mass of a U-235 atom is 235.0439.

4. Atomic Weight

a. Average weight of an element based on the percent abundance of its naturally occurring isotopes

(1) using $^{13}_{6}C$ and $^{12}_{6}C$

(2) 12.00 (0.989) + 13.00 (0.011) = 11.868 + 0.143 = 12.011 amu.

b. Units are expressed in AMU

c. Used in calculations of chemical reactions

G. Nuclide Notation — Objective 1.03.07

1. $^{A}_{Z}X$ format where:

a. X is the symbol for the element.

b. Z is the atomic number - the number of protons.

c. A is the mass number - number of protons (Z) plus the number of neutrons (N); therefore, A=Z+N

2. Uranium-238 would be written $^{238}_{92}U$

H. Modern Periodic Table

See Fig. 5 - "Periodic Table of The Elements"

1. The modern Periodic Table is an arrangement of the elements in order of increasing atomic number. A comparison of the properties for selected elements will illustrate that there is a predictable, recurring pattern (periodicity). This observation is summarized in the Periodic Law - the properties of the elements are repetitive or recurring functions of their atomic numbers.

Objective 1.03.08

2. Data about each element in the Periodic Table are present in a column and row format. The rows or horizontal sections in the Periodic Table are called periods. The columns or vertical sections in the Periodic Table are called groups or families.

Objective 1.03.09

3. The structure of the Periodic Table is directly related to the arrangement of electrons in the atoms.

See Table 3 - "Electron Configuration of the Elements"
See Fig. 4 - "Electron Shells"

4. Electrons orbit around the nucleus in structured shells, designated sequentially as 1 through 7 (K through Q) from inside out. Shells represent groups of energy states called orbitals. The higher the energy of the orbital the greater the distance from the nucleus. The lowest energy state is in the innermost shell (K).

5. The number of orbitals in a shell is the square of the shell number (n). The maximum number of electrons which can occupy an orbital is 2. Therefore, each shell can hold a maximum of $2n^2$ electrons. For example, for the L shell the maximum number of electrons would be 8:

L-shell: $n = 2$ YYY $2(2^2) = 8$

Objective 1.03.10

6. The highest occupied energy level in a ground-state atom is called its valence shell. Therefore, the electrons contained in it are called valence electrons. The rows or periods in the Periodic Table correspond to the electron shells. The elements contained in first period have their valence electrons in the first energy level or K-shell. The elements contained in the second period have their outer or valence shell electrons in the second energy level or L-shell, and so on.

7. The number of electrons in the valence shell determines the chemical properties or "behavior" of the atom. The valence shell can have a maximum of eight electrons, except for the K-shell which can only have two. Atoms are chemically stable when the valence shell has no vacancies; that is, they "prefer" to have a full valence shell. Atoms of elements toward the right of the Periodic Table seem to lack only one or two electrons. These will "look" for ways to gain electrons in order to fill their valence shell. Atoms of elements on the left side of the table seem to have an excess of one or two electrons. These will tend to find ways to lose these excess electrons so that the full lower shell will be the valence shell.

8. The outcome is that certain atoms will combine with other atoms in order to fill their valence shells. This combination that occurs is called a chemical bond, and results in the formation of a molecule. The bond is accomplished by "sharing" or "giving up" valence electrons, thus forming a molecule whose chemical properties are different than those of the individual element atoms.

   a. Good example - table salt

9. Note the right most column in the Periodic Table. These elements are known as the noble or inert gases because they all have a full valence shell. This means that they "feel" no need to bond with other atoms. Noble gases are thus considered chemically inert and very rarely interact with other elements.

10. The Quantum Mechanical Model

    a. Over the years, the Bohr model of the atom was found to be inadequate as the principles of quantum mechanics evolved. A newer model, known as the quantum mechanical model, describes the electrons arranged in energy levels corresponding to the "electron shells" of the Bohr model. In the quantum mechanical model the electron is not viewed as particle in a specific orbit, but rather as an electron cloud in which the negative charge of the electron is spread out within the cloud. These energy levels are referred to as orbitals to emphasize that these are not circular "orbits" like those of the Bohr model but rather electron clouds. An electron cloud is a representation of the volume about the nucleus in which an electron of a specific energy is likely to be found.

b. The quantum mechanical model further states that the energy levels are subdivided into sublevels, referred to by the letters *s*, *p*, *d* and *f*. An energy level can contain 1 to 4 sublevels or orbitals, and a maximum of two electrons can reside in each sublevel. For example, the first energy level contains one *s* sublevel which can accommodate a maximum of two electrons.

III. SUMMARY

A. Review major topics

1. Physics definitions

2. Law of Conservation of Energy

3. The Atom

4. Periodic Table

5. Valence Electrons

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

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